MULTIMEDIA UNIVERSITY®

STUDENT ID NO

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# MULTIMEDIA UNIVERSITY

# FINAL EXAMINATION

**TRIMESTER 1, 2022/2023 (TERM ID 2210)**

## EMF2016 ELECTROMAGNETIC THEORY

(All Sections / Groups)

7 FEBRUARY 2023
2.30 P.M – 4.30 P.M.
(2 Hours)

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**INSTRUCTIONS TO STUDENTS**

1. This question paper consists of 12 pages including this cover page with 4 questions only. Common constants for air are listed on Page 4. Equations are listed on Page 5,6 and 7.

2. Attempt all four questions. All questions carry equal marks and the distribution of marks for each question is given.

3. Please print all your answers in the answer booklet provided.

4. Please tie and submit worked Smith charts together with the answer booklet.

**Question 1 (25 marks)**

An antenna with an impedance of $(45 + j50)\ \Omega$ terminates a $140\ \Omega$ lossless transmission line. A standing wave is observed along the transmission line, indicating the mismatch condition.

(a) If the period of the standing wave is 5 cm, without using a Smith chart, determine:

(i) The reflection coefficient at the load.

[4 marks]

(ii) The standing wave ratio.

[2 marks]

(iii) The position of the voltage maximum nearest to the load

[3 marks]

(b) Using a smith chart, determine:

(i) The input admittance at the location $0.7\lambda$ from the load.

[6 marks]

(ii) The nearest location from the load to insert a matching element.

[6 marks]

(iii) The stub length to match the line with the antenna.

[4 marks]

**Question 2 (25 marks)**

(a) Describe Ampere's Law and write the Maxwell's equation that represent it.

[4 marks]

(b) A 50 turns coil wrapped around a square frame of sides 0.3 m. The coil is centered at the origin with each of its sides parallel to the $x$ or $y$-axis. A magnetic field $\vec{B}$ is given by

$$\vec{B} = \hat{z}\ 10\ \cos y \cos 10^3\, t\ (\mathrm{T}).$$

Determine:

(i) The induced electromotive force (emf) across a small gap created in the loop.

[10 marks]

(ii) The current and its direction at the time just after t = 0, if the resistor connected across the gap is $2k\Omega$.

[3 marks]

**Continued ...**

(c) **Figure Q2(b)** shows a 30-cm-long conducting rod rotates about the z-axis at $150\pi$ rad/minute, with end 1 fixed at the origin. If the magnetic field $\vec{B} = -\hat{z}\,16\,mT$, determine the induced emf $V_{12}$.

[8 marks]

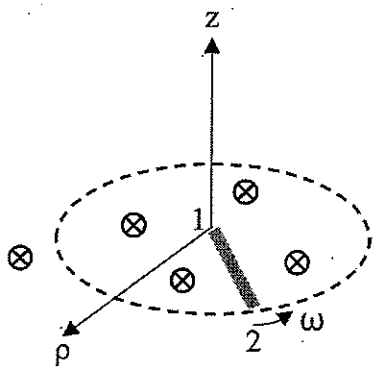


**Figure Q2(b)**

**Question 3 (25 marks)**

(a) The electric field of a uniform plane wave propagating in a nonmagnetic material ($\mu_r = 1$, $\varepsilon_r = 2.3$) is given by

$$\boldsymbol{E} = 5\,cos(20 \times 10^6 \pi t - 0.318z)\hat{x} + 5\,sin(20 \times 10^6 \pi t - 0.318z)\hat{y}\ \text{V/m}$$

Determine:

(i) The phase velocity.

[2 marks]

(ii) The wavelength.

[2 marks]

(iii) The wave impedance.

[2 marks]

(iv) The polarization of the wave.

[4 marks]

(v) The corresponding magnetic field $\boldsymbol{H}$.

[5 marks]

(vi) The time-averaged power density.

[4 marks]

(b) A sample of wet soil has $\mu_r = 1$, $\varepsilon_r = 9$ and $\sigma = 0.01$ S/m at 3 GHz. Estimate the skin depth $\delta$ of the soil at 3 GHz.

[6 marks]

**Continued ...**

**Question 4 (25 marks)**

(a) A uniform plane wave has electric field, $\boldsymbol{E} = 12\cos(\omega t - kz)\hat{\boldsymbol{y}}$ V/m in free space ($z \leq 0$) hits a magnetic medium with dielectric constant with $\epsilon_r = 9$, $\mu_r = 30$ and conductivity, $\sigma = 0$ which occupies $z \geq 0$.

Determine:

(i) The transmission coefficient, $\tau$.

[5 marks]

(ii) The time-average power density of the transmitted plane wave.

[3 marks]

(b) An air-filled rectangular waveguide has a cross section dimension of 58 mm × 29 mm, and length of 1.0 m.

(i) State the propagation modes with the lowest and the second lowest cut-off frequencies. Also determine the cut-off frequencies.

[6 marks]

(ii) Suggest a suitable operating frequency range, $f_{o(min)}$ and $f_{o(max)}$, for this rectangular waveguide. The operating frequency $f_o$ should be within $f_{o(min)} < f_o < f_{o(max)}$. Support your suggestion with a brief explanation. *[Hint: you may give two reasons why this range of frequency is recommended, covering factors like frequency margin, group velocity or dispersion]*

[6 marks]

(iii) Assuming the operating frequency is at the mid-point of your suggested frequency range, i.e. $f_o = (f_{o(min)} + f_{o(max)})/2$. If the EM wave within the rectangular waveguide is modulated with information, determine how long it would take for the information to travel from one end to the other end of the rectangular waveguide. *[Hint: work out the group velocity at $f_o$]*

[5 marks]

**Common constants for air**

| | |
|---|---|
| Speed of light, $c$ | $= 3 \times 10^8$ m/s |
| Permittivity, $\varepsilon_0$ | $= 8.854 \times 10^{-12}$ F/m |
| Permeability, $\mu_0$ | $= 4\pi \times 10^{-7}$ H/m |
| Intrinsic impedance, $\eta_0$ | $= 377\ \Omega$ |

**Continued ...**

## Equations

### Transmission Line

Transmission Line Parameters

| Parameter | Coaxial Line | Two Wire |
|---|---|---|
| $R'$ | $\frac{R_s}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$ | $\frac{R_s}{\pi a}$ |
| $L'$ | $\frac{\mu}{2\pi}ln\left(\frac{b}{a}\right)$ | $\frac{\mu}{\pi}ln\left[\left(\frac{d}{2a}\right)+\sqrt{\left(\frac{d}{2a}\right)^2-1}\right]$ |
| $G'$ | $\frac{2\pi\sigma}{ln\left(\frac{b}{a}\right)}$ | $\frac{\pi\sigma}{ln\left[\left(\frac{d}{2a}\right)+\sqrt{\left(\frac{d}{2a}\right)^2-1}\right]}$ |
| $C'$ | $\frac{2\pi\varepsilon}{ln\left(\frac{b}{a}\right)}$ | $\frac{\pi\varepsilon}{ln\left[\left(\frac{d}{2a}\right)+\sqrt{\left(\frac{d}{2a}\right)^2-1}\right]}$ |
| $R_s=\sqrt{\frac{\pi f\mu_c}{\sigma_c}}$ | | |

$$u_p=\frac{\omega}{\beta}=f\lambda=\frac{1}{\sqrt{\mu\varepsilon}} \qquad \beta=\frac{2\pi}{\lambda}$$

$$\gamma=\alpha+j\beta=\sqrt{(R'+j\omega L')(G'+j\omega C')} \qquad Z_0=\sqrt{\frac{R'+j\omega L'}{G'+j\omega C'}}$$

Lossless:

$\gamma=j\omega\sqrt{L'C'}$, $Z_0=\sqrt{\frac{L'}{C'}}$

Distortionless:

$\gamma=\sqrt{R'G'}+j\omega\sqrt{L'C'}$, $Z_0=\sqrt{\frac{L'}{C'}}$

$$Z_{in}(l)=Z_0\frac{Z_L+jZ_0\tan\beta l}{Z_0+jZ_L\tan\beta l} \qquad Z_{in}^{sc}(l)=jZ_0\tan\beta l$$

$$Z_{in}^{oc}(l)=-jZ_0\cot\beta l \qquad Z_0=\sqrt{Z_{in}^{sc}Z_{in}^{oc}}$$

$$Z_{in}\left(\frac{\lambda}{4}\right)=\frac{Z_0^2}{Z_L} \qquad \tan(\beta l)=\sqrt{-\frac{Z_{in}^{sc}}{Z_{in}^{oc}}}$$

**Continued ...**

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$P_{i,av} = \frac{|V_0^+|^2}{2Z_0}$$

$$P_{r,av} = |\Gamma|^2 \times P_{i,av}$$

$$SWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$d_{max} = \frac{\theta_\Gamma \lambda}{4\pi} + \frac{n\lambda}{2}$$

$$d_{min} = d_{max} \pm \frac{\lambda}{4}$$

**Maxwell's Equations**

$$\nabla . \mathbf{D} = \rho_v \qquad \nabla . \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \qquad \nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\Psi = \int \boldsymbol{B}.d\boldsymbol{s} \qquad V_{emf} = -N\frac{d\Psi}{dt} = -N\frac{d}{dt}\int \boldsymbol{B}.d\boldsymbol{s}$$

$$V_{emf}^m = \oint (\boldsymbol{u} \times \boldsymbol{B}) \cdot d\boldsymbol{l} \qquad \underline{\mathbf{F}} = \underline{\mathbf{F}}_m + \underline{\mathbf{F}}_e = q(\underline{\mathbf{v}} \times \underline{\mathbf{B}} \times \underline{\mathbf{E}})$$

**Uniform Plane Wave**

$u_p = \frac{\omega}{k} = \frac{1}{\sqrt{\mu\varepsilon}}$

$\lambda = \frac{2\pi}{k} = \frac{u_p}{f}$

$\tilde{\mathbf{H}} = \left(\frac{1}{\eta}\right)\hat{\mathbf{k}} \times \tilde{\mathbf{E}}$

$\tilde{\mathbf{E}} = -\eta\hat{\mathbf{k}} \times \tilde{\mathbf{H}}$

$\eta = \sqrt{\frac{\mu}{\varepsilon}}$

$\boldsymbol{S}_{ave} = \frac{1}{2\eta}|\tilde{E}|^2\hat{k}$

Lossy medium:

$\varepsilon_c = \varepsilon - j\frac{\sigma}{\omega} = \varepsilon' - j\varepsilon''$

$\eta_c = \sqrt{\frac{\mu}{\varepsilon'}}\left(1 - \frac{\varepsilon''}{\varepsilon'}\right)^{-\frac{1}{2}}$

$\gamma = \alpha + j\beta \qquad u_p = \frac{\omega}{\beta}$

$\delta_s = \frac{1}{\alpha}$

Low-loss dielectric:

$\alpha \cong \frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}} \quad \beta \cong \omega\sqrt{\mu\varepsilon} \quad \eta_c \cong \sqrt{\frac{\mu}{\varepsilon}}$

**Continued ...**

Good conductor:

$\alpha \cong \sqrt{\pi f \mu \sigma} \quad \beta \cong \alpha \quad \eta_c \cong (1+j)\frac{\alpha}{\sigma}$

Normal Incidence

$\Gamma = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \quad \tau = \frac{2\eta_2}{\eta_2 + \eta_1} \quad \tau = 1 + \Gamma$

$\boldsymbol{S_{av1} = S_{av}^i + S_{av}^r} \quad \boldsymbol{S_{av}^r = -|\Gamma|^2 S_{av}^i} \quad \boldsymbol{S_{av1} = S_{av2}}$

**Waveguide**

$$f_{c_{mn}} = \frac{u_{p_0}}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \qquad \beta_{mn} = \beta_0\sqrt{1 - \left(\frac{f c_{mn}}{f}\right)^2}$$

$$u_p = \frac{u_{p0}}{\sqrt{1 - \left(\frac{f c_{mn}}{f}\right)^2}} \qquad u_g = u_{p0}\sqrt{1 - \left(\frac{f c_{mn}}{f}\right)^2}$$

$$Z_{TM} = \eta\sqrt{1 - \left(\frac{f c_{mn}}{f}\right)^2} \qquad Z_{TE} = \frac{\eta}{\sqrt{1 - \left(\frac{f c_{mn}}{f}\right)^2}}$$

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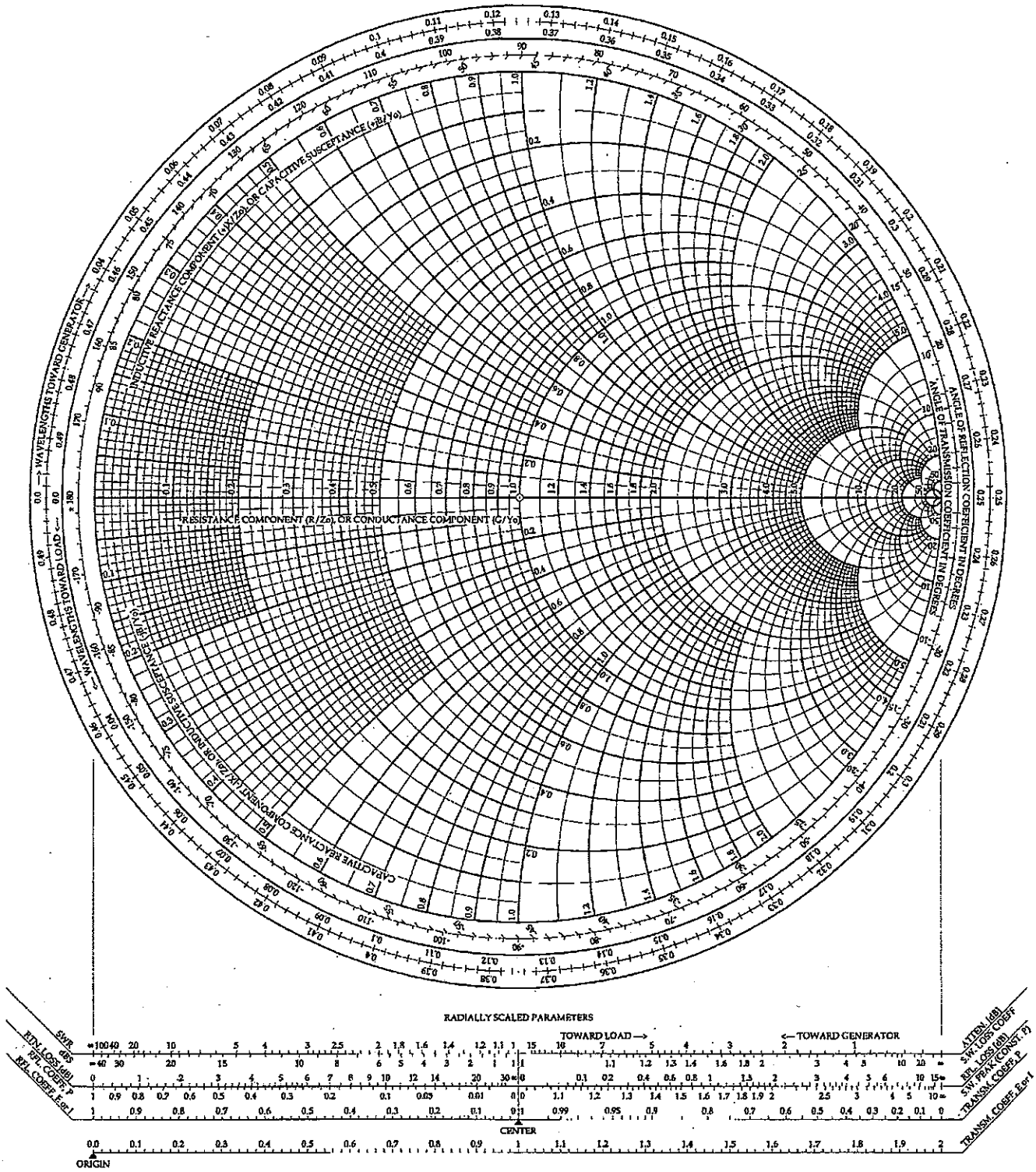
# The Complete Smith Chart

## Black Magic Design

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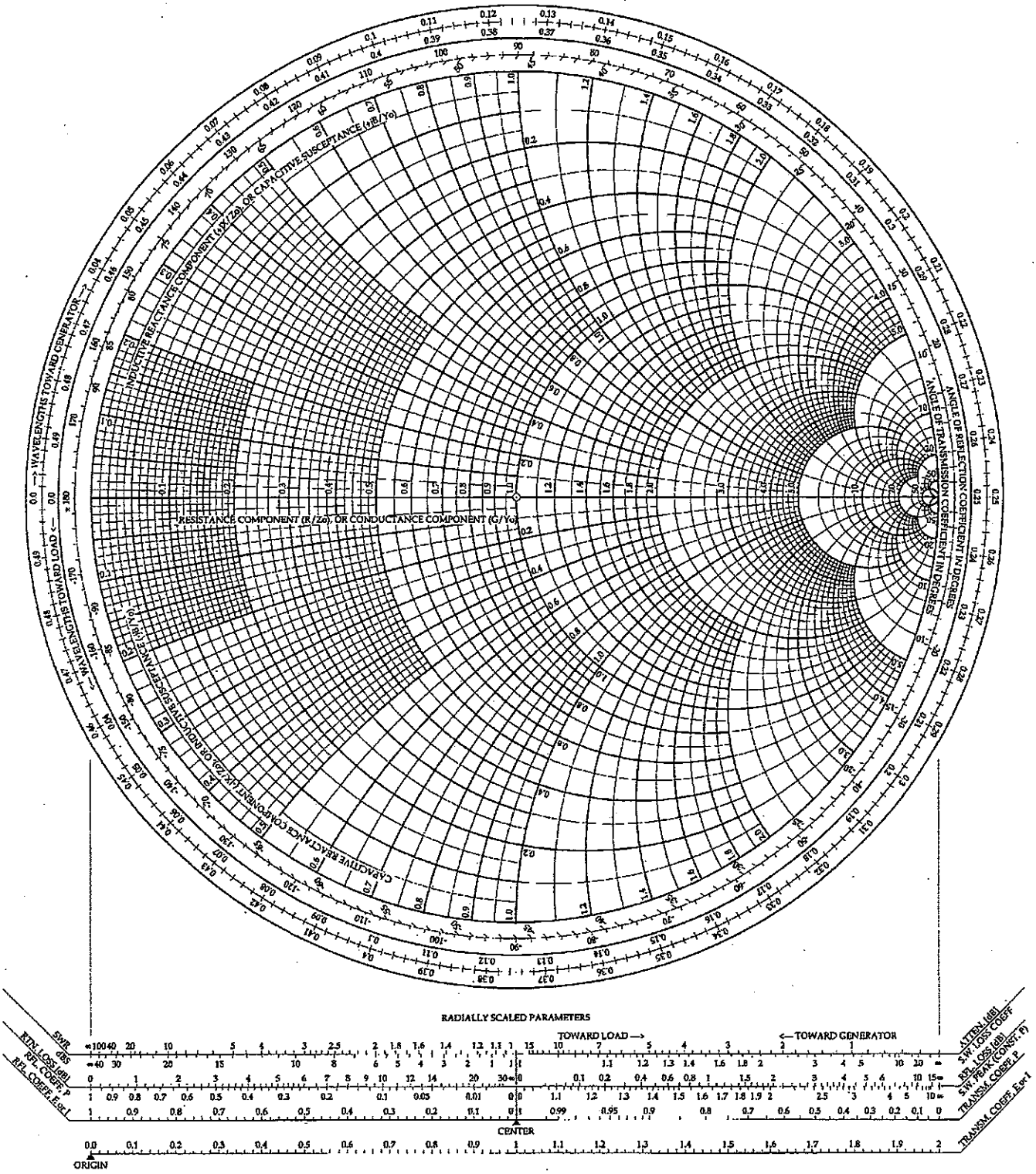


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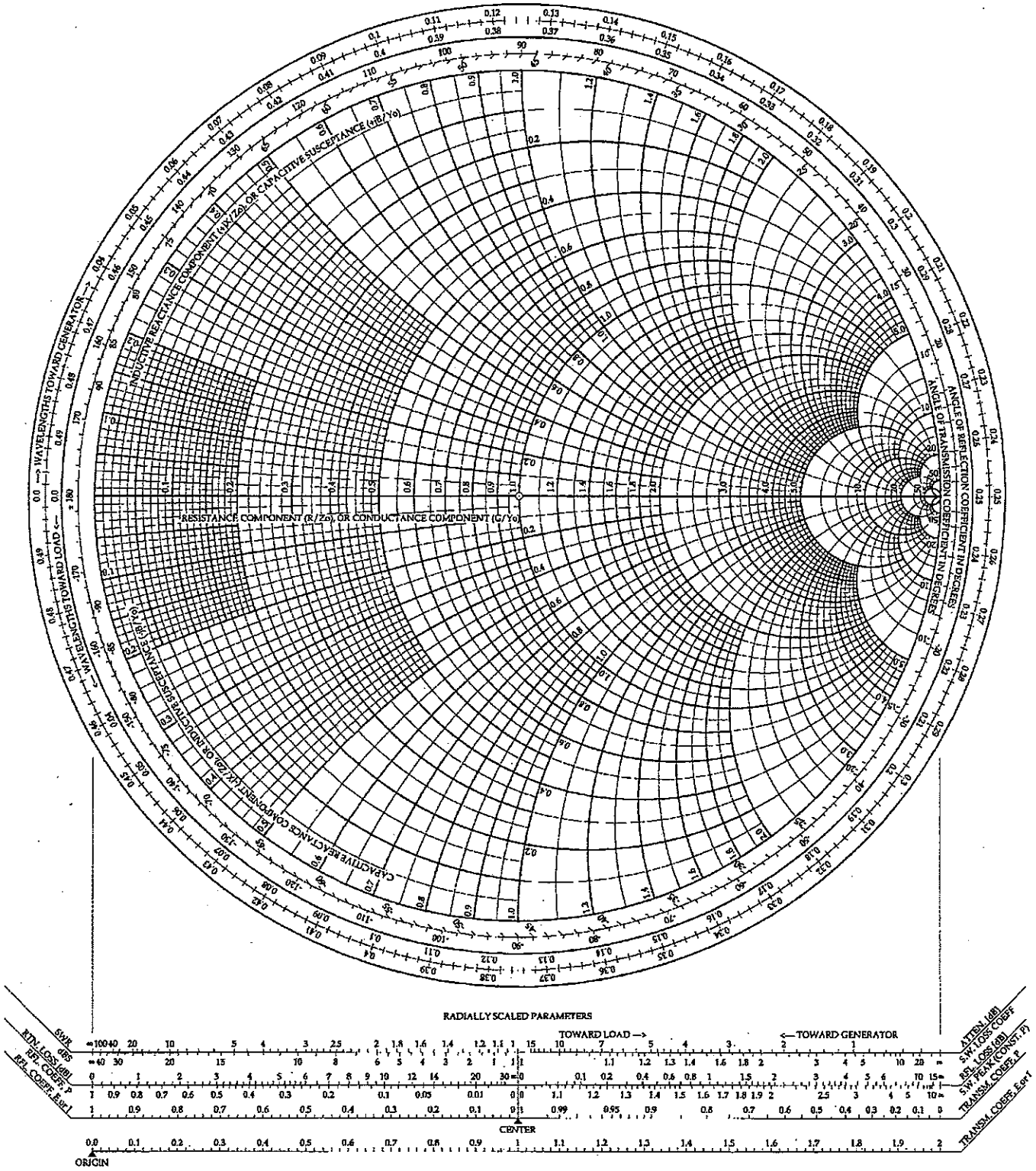


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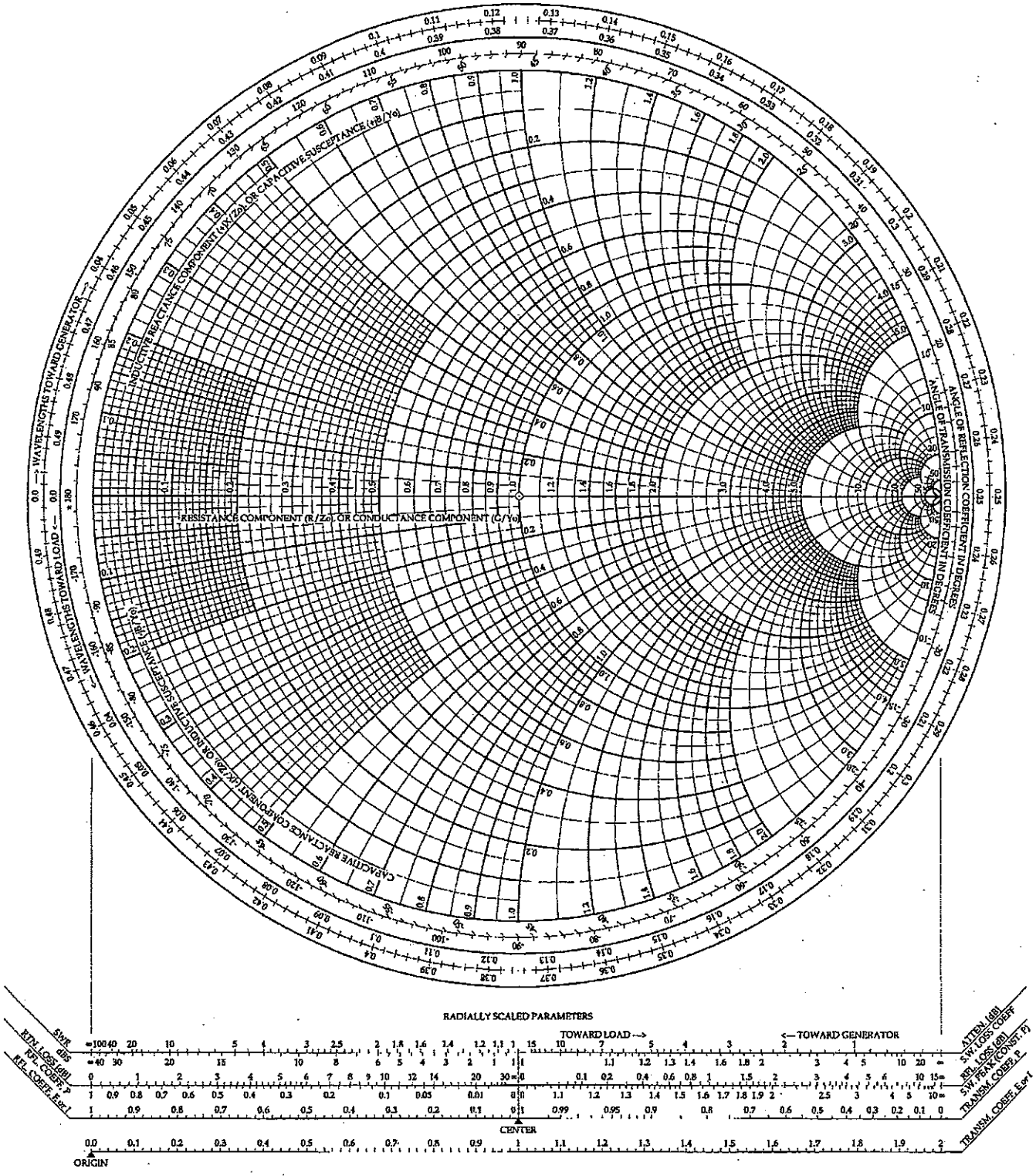


http://www.sss-mag.com/pdf/smithchart.pdf

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